Bermudagrass–White Clover–Bluegrass Sward Production and Botanical Dynamics

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ABSTRACT

Cool-season forages dominate pastures in the Appalachian region where midsummer weather conditions often depress productivity. Warm-season forages can buffer variation in available herbage, but land resources may limit the area dedicated to special-use crops. A replicated field plot experiment was conducted for 3 yr (1995–1997) in a bermudagrass (*Cynodon dactylon* L.) stand oversown with Kentucky bluegrass (*Poa pratensis* L.) and white clover (*Trifolium repens* L.) to determine the influence of defoliation on productivity, nutritive value, and botanical dynamics of the mixture. Botanical composition changed with defoliation and varied among years. Bermudagrass comprised as much as 55% of the sward in mid- and late-season 1995. By 1997, the proportion was similar to other grasses and rarely exceeded 20%. Maximum instantaneous growth rates occurred later in the growing season in 1995 when bermudagrass was a dominant sward component compared with subsequent years when bermudagrass was <10% of the sward. Rates in 1995 were greatest for swards clipped at 6-wk intervals (70 kg ha^{-1} d^{-1}) or when 20-cm tall and least when clipped at 2-wk intervals (33 kg ha^{-1} d^{-1}) and at 10-cm height (45 kg ha^{-1} d^{-1}). The trend was reversed by 1997 when sward composition shifted away from bermudagrass to cool-season grasses and white clover. Yields were greatest when cool-season species dominated the sward. Creating a self-regulating mixture of warm- and cool-season perennial forages may be a means of achieving some stability in sward productivity and might be useful where wide fluctuations in growing conditions occur among years.

A PRINCIPAL GOAL in pasture management is production of a reliable supply of high quality available forage throughout the growing season. Pastures in the Appalachian region are dominated by cool-season forage species, but periodic drought and elevated temperatures in midsummer often depress productivity. Warm-season forages might help buffer variation in available herbage (George et al., 1995; Jung et al., 1985; Madakadze et al., 1998; Posler et al., 1993) because of greater water, light, and N-use efficiencies (Belesky and Fedders, 1995a) and higher temperature optima compared with cool-season forages.

The production season for warm-season grasses is relatively short in the northeastern USA and ranges from 90 to 110 d in the central Appalachian highlands, depending on the occurrence of frost (Belesky and Fedders, 1995b). Growth usually begins in mid-May and slows as nighttime temperatures decline in late August. Elevation and slope aspect influence species adaptation and growth and the duration of the growing season (Bennett et al., 1976). Optimum growing conditions for certain species may arise from disturbances created by management practices and short-term weather conditions at a particular site (White et al., 1997). Defoliation frequency influences forage productivity and can influence the relative growth rate and productivity of cool- and warm-season grasses in the central Appalachian highlands (Belesky and Fedders, 1995b). Cool-season grasses often invade warm-season swards in the region because rapid growth of cool-season species in spring leads to vigorous competition and suppression of warm-season plants that begin growing at a later time.

A mixture of forages with the ability to exploit resource patches in the sward could allow for rapid adjustment to changing management and growing conditions and perhaps stabilize supply of available herbage. Livestock grazing complicates the situation because the distribution of nutrients via manure deposition creates resource patches in a pasture. Grazing behavior also creates gaps in the canopy or causes differential defoliation pressure on various species in the sward. Plants capable of exploiting patches and able to tolerate grazing should have a competitive advantage in pasture. Likewise, the pasture manager would have greater flexibility or reassurance that some component of the sward is likely to be productive under a wide range of conditions.

Dedicating land resources to pure stands of warm-season forage may not be practical on many small-scale farming operations. Overseeding warm-season swards with cool-season annuals such as annual ryegrass (*Lolium multiflorum* L.) or small grains is a common practice in the southeastern USA. Some examples of compatible warm-season grasses and cool-season legumes include combination of sweetclover (*Melilotus* spp.), hairy vetch (*Vicia villosa* L.), birdsfoot trefoil (*Lotus corniculatus* L.), red clover (*Trifolium pratense* L.), or crownvetch (*Coronilla varia* L.) with switchgrass (*Panicum virgatum* L.) (George et al., 1995; Jung et al., 1985); alfalfa (*Medicago sativa* L.) and bermudagrass (Brown and Byrd, 1990); and white clover and bermudagrass (Brink and Fairbrother, 1991). Grass–legume combinations offer improved seasonal distribution of herbage yield, a source of N from fixation for enhanced grass production, and the potential for high nutritive value (Sleugh et al., 2000); however, very little is known about forage mixtures including both cool (C_3)- and warm (C_4)-season perennial grasses and a cool-season legume.

A mixed stand of bermudagrass, Kentucky bluegrass, and white clover was used to determine if a mixture of C_3 and C_4 grasses and a legume, each with either rhizomatous or stoloniferous growth habit, would result in a dynamic array of plants capable of sustained herbage production over the growing season. We documented yield changes in botanical composition of the sward as well as nutritive value as influenced by canopy management, time, and microclimate conditions occurring each growing season. Observations were made

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Published in Agron. J. 94:575–584 (2002).

Abbreviations: ADG, average daily gain; IGR, instantaneous growth rate; IVOMD, in vitro organic matter disappearance; S50, 10-cm canopy clipped to 5-cm residue; T75, 20-cm canopy clipped to a 5-cm residue; 2WK, clipped at 2-wk intervals to a 5-cm residue; 6WK, clipped at 6-wk intervals to a 5-cm residue.

on growing lamb (*Ovis* spp.) performance when grazing the mixed sward.

MATERIALS AND METHODS

Site Preparation

A replicated field plot experiment was established in a bermudagrass pasture oversown with Kentucky bluegrass and white clover. The study was conducted for three consecutive years (1995–1997) under field conditions on a 0.4-ha area in the Eastern Allegheny Plateau and Mountain region in southern West Virginia (38° N, 81° W; 850 m above sea level). 'Quickstand' bermudagrass was established in 1993 on a Dekalb series soil (loamy-skeletal, mixed, mesic Typic Dystrochrept) that was free draining and on a relatively level (<3% slope) site. The area was sprayed with glyphosate [N-(phosphono-methyl) glycine] at 1.19 kg ha^{-1} a.i. in early May of 1993 and again 2 wk later to control existing vegetation. The area used for the plot experiment was tilled, with one-third of the area planted manually in mid June 1993 with bermudagrass plugs. The remaining two-thirds of the area was planted mechanically using stolons collected from an existing bermudagrass sward. Stolons were broadcast with a manure spreader over the newly tilled paddock area, lightly disced into the soil, and then cultipacked. The area was sprayed with 2,4-diamine (2,4-dichorophenoxyacetic acid) at 4 L ha^{-1} in mid- and late June to control broadleaf weeds and in July with dicamba (dimethylamine salt of 2-methoxy-3,6-dichloro-*o*-anisic acid) at 1.16 L ha^{-1} to control horse nettle (*Solanum carolinense* L.). No other pesticides were applied to the site for the duration of study. The entire area received 100 kg N ha^{-1} as ammonium nitrate (NH_4NO_3) in late July 1993.

The entire area was oversown in late August with annual ryegrass at 30 kg ha^{-1} as a cover for the establishing bermudagrass sod and to provide fall grazing in 1993 and early spring grazing in 1994. A single application of 224 kg ha^{-1} N–P–K (19–19–19) was made each spring beginning in 1994. Before the initial grazing in April of 1994, 'Huia' white clover and Kentucky bluegrass were broadcast-seeded at 3.5 and 5 kg ha^{-1}, respectively, so that grazing animals could tread the seed into the soil.

Treatments and Sample Collection

Plots were established within the paddock area in spring of 1995 in an area excluded from grazing livestock. Each plot was 2 by 3 m, with four plots in each of three replicate blocks for a total of 12 plots. Four defoliation regimes were imposed: temporal-based treatments [clipped to a 5-cm residue at 2-wk (2WK) and 6-wk (6WK) intervals] or environmental-based treatments [a 10-cm canopy clipped to 5-cm residue (S50) and a 20-cm canopy clipped to a 5-cm residue (T75; tall canopy with 75% removal)]. Sample strips (0.6 by 2 m) were clipped from the center of each plot using a rotary mower equipped with a collection bag. Herbage from the entire sample strip was dried at 60°C in a forced-air oven for at least 48 h, and dry matter was determined. Dried tissue samples ground to pass a 2-mm screen were used for nutritive value determination. Parameters included ash (AOAC, 1990), in vitro organic matter disappearance (IVOMD) (Tilley and Terry, 1963; Moore, 1970), and total N with a Carlo Erba EA 1108 CHNSO analyzer[1] (Fisons Instruments, Beverly, MA). Crude protein was expressed as N × 6.25. The IVOMD procedure used rumen fluid obtained from two rumen-cannulated steers offered orchardgrass (*Dactylis glomerata* L.) and alfalfa hay.

Botanical composition was determined before each harvest using the point-quadrat method described by Warren-Wilson (1959). Each of 81 contact points in a plot was categorized as bermudagrass, bluegrass, orchardgrass, tall fescue (*Festuca arundinacea* Schreb.), velvetgrass (*Holcus lanatus* L.), white clover, other taxa (includes forbs and other grasses not listed above), and senesced material.

[1] Trade names do not imply endorsement by USDA-ARS over comparable products.

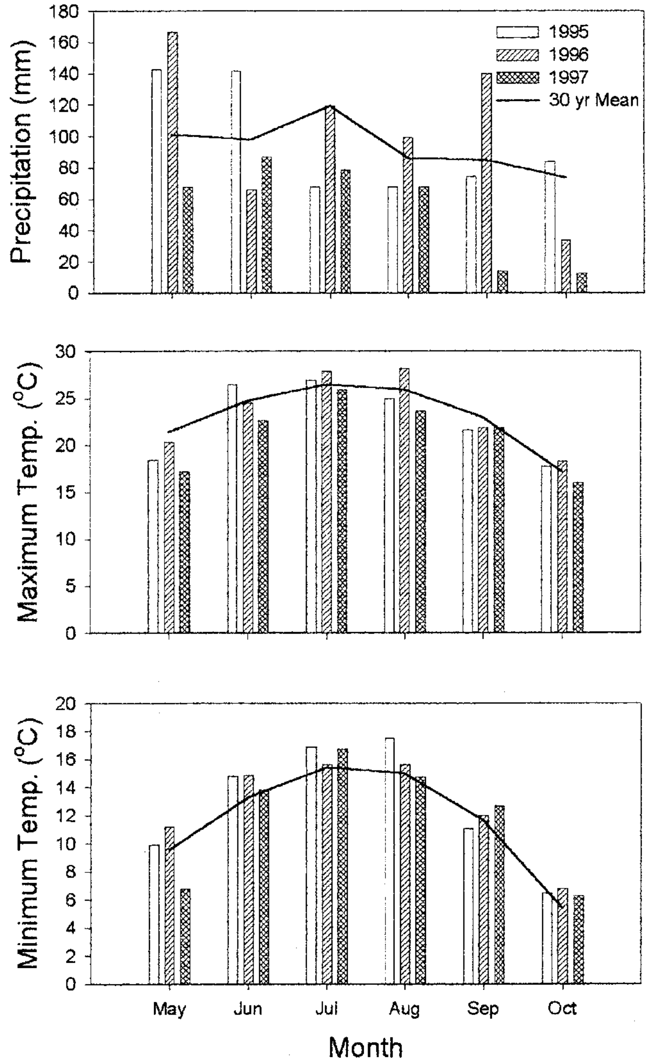

Fig. 1. Mean monthly maximum and minimum air temperatures, monthly precipitation, and 30-yr mean values for each parameter at Beckley, WV (37°45′ N, 81°15′ W; 850 m above sea level).

Grazing

Eighteen Hereford steers (*Bos taurus*) were turned out in mid-April of 1994 to graze the spring flush of ryegrass and volunteer cool-season species and winter annuals. The cattle remained on the 0.4-ha site for 6 d and grazed until a mean residual herbage height of 10 cm was obtained. The cattle were removed from that site to an adjacent orchardgrass–white clover pasture, at which time any forage not grazed to the 10-cm residue was clipped to the target canopy height. In mid-June, steers returned to the area to graze the regrowth and remained on the area for 5 d, until the target residue height of 10 cm was achieved. Vigorous bermudagrass growth was occurring by this time. The area was subdivided into three 0.12-ha paddocks, and herbage mass was estimated by clipping three strips (0.6 by 2 m) in each paddock to a 5-cm residue height. On 5 July 1994, growing lambs (mean mass of 41 kg) began grazing the three paddocks for a total of 17 d at 152 animals ha^{-1}

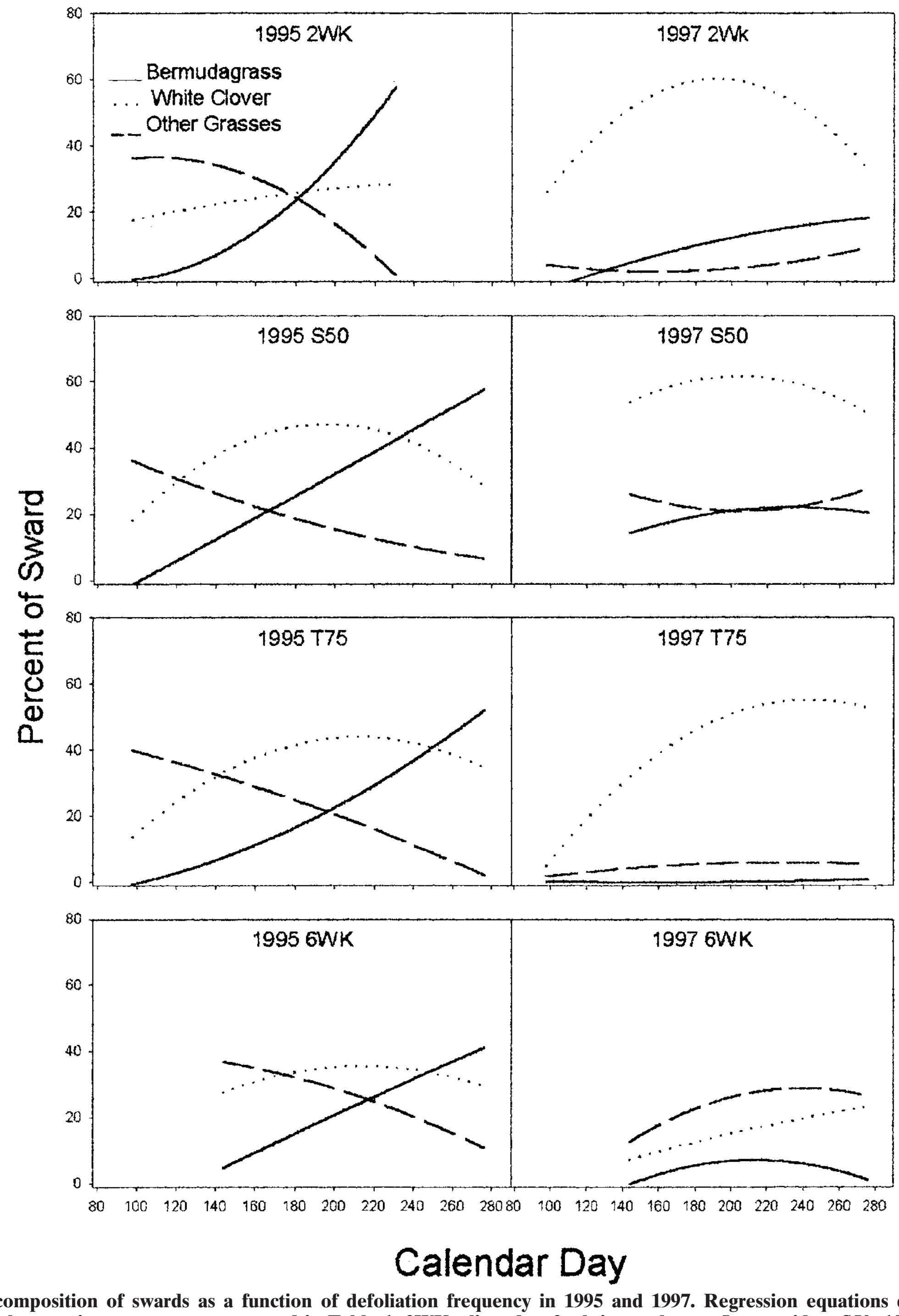

Fig. 2. Botanical composition of swards as a function of defoliation frequency in 1995 and 1997. Regression equations describing botanical composition in the growing seasons are presented in Table 1. 2WK, clipped at 2-wk intervals to a 5-cm residue; S50, 10-cm canopy clipped to 5-cm residue; T75, 20-cm canopy clipped to a 5-cm residue; 6WK, clipped at 6-wk intervals to a 5-cm residue.

based on herbage mass. Lambs grazed a paddock to a 5-cm residue canopy height and were then moved to the next paddock. After completing the cycle on bermudagrass, the animals were moved to an adjacent orchardgrass–white clover area. Lambs, averaging 43 kg, began the second interval on 28 July, with 70 animals ha^{-1}, and grazed the three paddocks for 34 d.

Data Analysis

Data for cumulative yield and botanical composition were analyzed as a randomized complete block design using SAS-MIXED procedure (Littell et al., 1996). Canopy management and harvest dates were considered fixed and replication random effects in the model. Years were analyzed separately for cumulative yield within the mixed model because chi-squared test for cumulative yield and botanical composition indicated heterogeneity of variance. Denominator degrees of freedom were calculated using the Satterthwaite option of MIXED analysis to determine the appropriate degrees of freedom. Treatment effects are considered significant at $P < 0.05$. Single degree-of-freedom contrasts were used to compare main-effect means. Botanical composition data were transformed (square root) before analyzing changes in sward composition over time and as a function of canopy management. Data

Table 1. Regression equations for the influence of day of year on botanical composition of the sward (percent of total composition) as a function of defoliation regime (temporal, 2WK and 6WK; or environmental, S50 and T75).†

2WK		
1995	Bermudagrass = $-58.97 + 0.7$ (date) $- 1.59 \times 10^{-3}$ (date)^2	$R^2 = 0.99$***
	White clover = $-25.77 + 0.3$ (date) $- 8.62 \times 10^{-4}$ (date)^2	$R^2 = 0.69$*
	Other grasses = $25.83 - 0.19$ (date) $+ 3.62 \times 10^{-4}$ (date)^2	$R^2 = 0.96$***
1997	Bermudagrass = $-15.00 + 0.16$ (date) $- 3.28 \times 10^{-4}$ (date)^2	$R^2 = 0.31$ NS‡
	White clover = $-3.88 + 0.18$ (date) $- 2.96 \times 10^{-4}$ (date)^2	$R^2 = 0.41$*
	Other grasses = $6.07 - 0.05$ (date) $+ 1.21 \times 10^{-4}$ (date)^2	$R^2 = 0.09$*
S50		
1995	Bermudagrass = $-6.1 + 0.8$ (date) $- 1.09 \times 10^{-4}$ (date)^2	$R^2 = 0.91$***
	White clover = $-5.16 + 0.11$ (date) $- 2.74 \times 10^{-4}$ (date)^2	$R^2 = 0.25$ NS
	Other grasses = $11.49 - 0.06$ (date) $+ 9.93 \times 10^{-5}$ (date)^2	$R^2 = 0.72$**
1997	Bermudagrass = $-11.51 + 0.12$ (date) $- 2.62 \times 10^{-4}$ (date)^2	$R^2 = 0.27$ NS
	White clover = $-0.33 + 0.07$ (date) $- 1.84 \times 10^{-4}$ (date)^2	$R^2 = 0.11$ NS
	Other grasses = $9.12 - 0.08$ (date) $+ 2.38 \times 10^{-4}$ (date)^2	$R^2 = 0.55$**
T75		
1995	Bermudagrass = $-4.53 + 0.06$ (date) $+ 4.54 \times 10^{-5}$ (date)^2	$R^2 = 0.89$***
	White clover = $-14.62 + 0.19$ (date) $- 4.49 \times 10^{-4}$ (date)^2	$R^2 = 0.42$ NS
	Other grasses = $22.14 - 0.16$ (date) $+ 3.05 \times 10^{-4}$ (date)^2	$R^2 = 0.62$*
1997	Bermudagrass = $1.75 + 0.01$ (date) $+ 3.73 \times 10^{-5}$ (date)^2	$R^2 = 0.41$ NS
	White clover = $3.89 + 0.02$ (date) $- 1.7 \times 10^{-5}$ (date)^2	$R^2 = 0.18$ NS
	Other grasses = $6.87 - 0.05$ (date) $+ 1.10 \times 10^{-4}$ (date)^2	$R^2 = 0.05$ NS
6WK		
1995	Bermudagrass = $-7.39 + 0.08$ (date) $- 1.27 \times 10^{-4}$ (date)^2	$R^2 = 0.17$**
	White clover = $-0.14 + 0.05$ (date) $- 9.97 \times 10^{-5}$ (date)^2	$R^2 = 0.07$ NS
	Other grasses = $12.42 - 0.06$ (date) $+ 8.69 \times 10^{-5}$ (date)^2	$R^2 = 0.43$ NS
1997	Bermudagrass = $-15.77 + 0.17$ (date) $- 4.15 \times 10^{-4}$ (date)^2	$R^2 = 0.50$ NS
	White clover = $-2.24 + 0.04$ (date) $- 3.76 \times 10^{-5}$ (date)^2	$R^2 = 0.23$ NS
	Other grasses = $-7.68 + 0.11$ (date) $- 2.46 \times 10^{-4}$ (date)^2	$R^2 = 0.50$ NS

* Significant at $P < 0.05$.
** Significant at $P < 0.01$.
*** Significant at $P < 0.001$.
† 2WK, clipped at 2-wk intervals to a 5-cm residue; S50, 10-cm canopy clipped to 5-cm residue; T75, 20-cm canopy clipped to a 5-cm residue; 6WK, clipped at 6-wk intervals to a 5-cm residue.
‡ NS, not significant.

presented are the original values. Annual herbage accumulation data were fit to Gompertz equation, which allows us to calculate an inflection point for instantaneous growth rate (IGR) (Draper and Smith, 1981):

$$\omega = \alpha \exp[-\beta \exp(-kt)] \quad [1]$$

where ω = herbage mass (kg ha^{-1} dry matter); t = day of year; and α (asymptotic yield), β (time function), and k (dimensionless) are calculated regression parameters. Instantaneous growth rates were calculated from first derivatives of cumulative yield fit to the Gompertz growth model (Hunt, 1982). Seasonal trends in growth rates were analyzed by covariance (homogeneity of slopes) procedures (Littell et al., 1996). Regression equations were generated using PROC REG (Littell et al., 1996) for bermudagrass, white clover, and grasses as a function of time across the growing season.

RESULTS AND DISCUSSION

Precipitation for the May to October growth interval at our location averages about 560 mm (30-yr mean). Cumulative precipitation and monthly distribution during the interval varied from year to year (Fig. 1). Total precipitation for the interval was 16 mm greater than the 30-yr mean in 1995, despite an 80-mm deficit occurring over June, July, and August. Mean precipitation was 63 mm greater than the 30-yr mean in 1996, with a 32-mm deficit occurring for June and July. The 1997 interval was very dry (−230 mm), with deficits relative to long-term means occurring in each month of the interval. Average maximum temperatures tended to vary only slightly relative to the 30-yr mean in 1995 and 1996 but were 2°C cooler in 1997. Maximum temperatures were less than the 30-yr mean in May each year and in June of 1996 and 1997. Minimum temperatures were slightly greater in 1995 and 1996 and similar in 1997 to the 30-yr mean.

Distribution of precipitation across the growing season is probably more important to consider than season-long mean as an influence on herbage production and botanical composition of mixed-species canopies (Dunnett and Grime, 1999). Dunnett and Grime (1999) found that interspecies competition modified and amplified response of individual species to conditions associated with surface soil warming, which suggests that growing conditions in spring set the stage for sward composition and herbage productivity for the rest of the season.

Botanical Composition

Bermudagrass was prominent in 1995 and when averaged over the growing season, comprised as much as 30% of the sward. In subsequent years, mean bermudagrass contribution declined to ≤10%. The decline in bermudagrass occurred in all clipping regimes; however, more bermudagrass was detected in 2WK than other treatments. We show data from 1995 and 1997 only to illustrate trends in sward composition as a function of years.

Botanical composition changed with the interaction of defoliation treatment and year (Fig. 2). Bermudagrass was minimal in T75 and 6WK canopies by 1997, suggesting that frequent, intensive removal (e.g., 2WK or S50) was required to favor bermudagrass growing in swards with species adapted to cool-temperate environments. This might not be a simple bermudagrass response per se but probably arises from interactions with weather patterns and competition among sward components. Means presented across a growing season obscure variation occurring with time across the season. For example, in 1995, bermudagrass increased while other grasses decreased within the growing season. The point where bermudagrass exceeded the contribution of other grasses occurred later in the season as clipping frequency decreased. As much as 55% of the sward in mid- and late season was bermudagrass when managed as

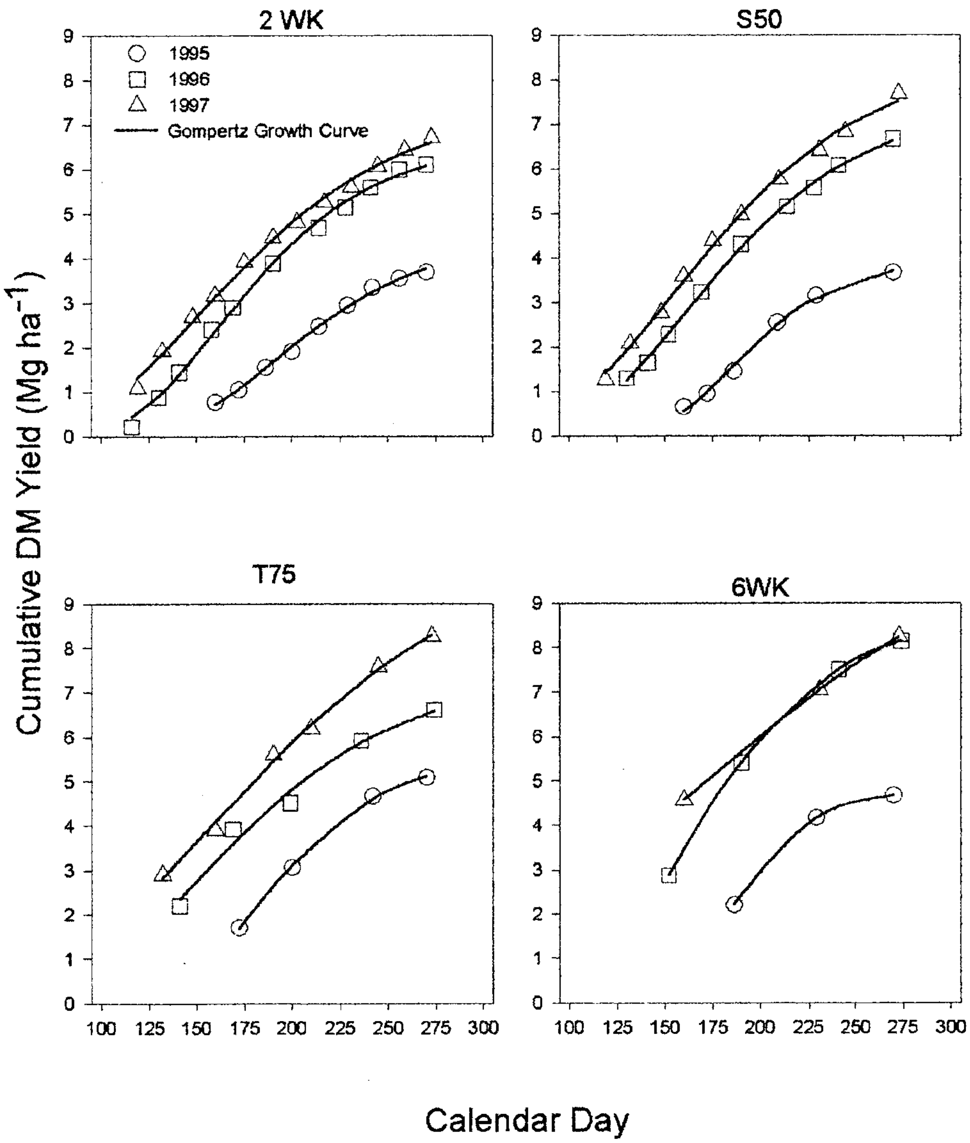

Fig. 3. Cumulative dry matter (DM) yield as a function of defoliation frequency for 1995 through 1997. Fitted lines are calculated from the Gompertz growth model. Regression parameters for the equations are presented in Table 3. 2WK, clipped at 2-wk intervals to a 5-cm residue; S50, 10-cm canopy clipped to 5-cm residue; T75, 20-cm canopy clipped to a 5-cm residue; 6WK, clipped at 6-wk intervals to a 5-cm residue.

S50 or 2WK canopies in 1995. By 1997, the proportion of bermudagrass was similar to other grasses and rarely exceeded 20%, with the most bermudagrass occurring in 2WK and S50 swards.

White clover increased to a midseason maximum and then decreased in late summer (Fig. 2) as a component of the sward when clipped at 2WK frequency (Table 1). There tended to be more clover in the sward in 1997 than in 1995 in all but 6WK canopies (Fig. 2). The mean contribution of white clover to sward cover increased from about 20% in 1995 to about 50% by 1997 in 2WK canopies. Increases occurred as the proportion of weeds, senesced herbage, and other grasses declined. Canopies clipped at 6WK intervals had the least and T75 the most white clover by the end of the experiment. Defoliation based on environmental criteria (S50 and T75) had a greater positive influence on white clover contribution to the sward than clipping based on time (2WK or 6WK). The contribution of white clover to sward mass may be overestimated because clover leaves cover a greater horizontal area than the erect leaves of grasses, and therefore are more likely to be detected with the point-quadrat technique used to quantify botanical composition.

Bluegrass increased as a botanical component from essentially none in 1995 to about 10% by 1997. Because there was so little bluegrass detected, it was difficult to explain apparent differences in terms of treatment. Differences attributable to defoliation were greatest in 1997, with more bluegrass in 2WK and S50 than in T75 canopies. Bluegrass was not detected in 6WK canopies probably because of competition for light exerted by taller species in the sward.

Other grasses occurring in the sward were native annual bluegrass (*Poa annua* L.) and 'Grasslands Matua' prairiegrass (*Bromus willdenowii* Kunth) sown at the site before the experiment presented here. These components declined from about 20% of the sward in 1995 to as little as 5% in 2WK canopies by 1997 (data not

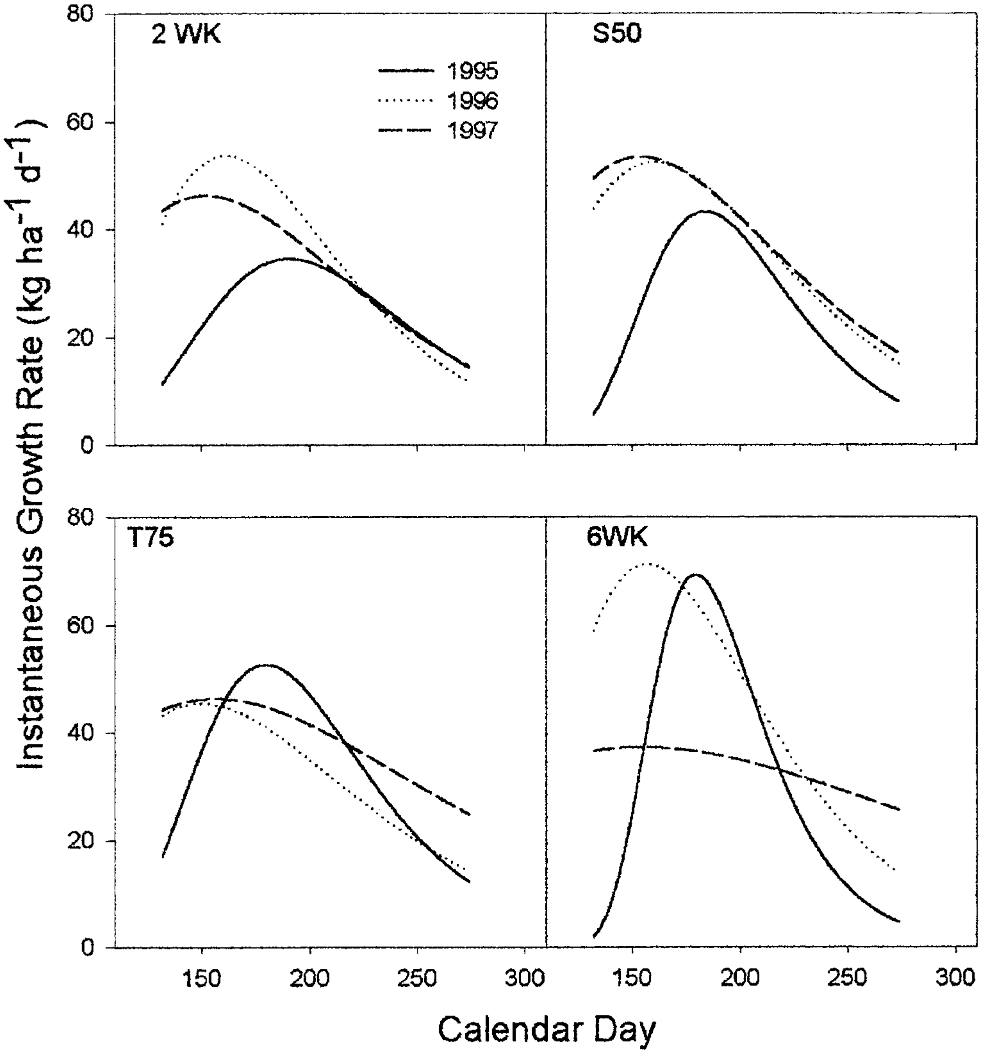

Fig. 4. Instantaneous growth rates (IGRs) of swards from 1995 through 1997 derived from the Gompertz growth model of cumulative yield as influenced by defoliation frequency. 2WK, clipped at 2-wk intervals to a 5-cm residue; S50, 10-cm canopy clipped to 5-cm residue; T75, 20-cm canopy clipped to a 5-cm residue; 6WK, clipped at 6-wk intervals to a 5-cm residue.

shown). The 6WK treatment was the exception in that other grasses comprised about 45% of the sward by 1997. Time-dependent treatments (2WK and 6WK) had greater amounts of weeds than did canopies clipped as S50 and T75. Trends in response of a given botanical component, especially T75 and 6WK treatments, over time tended to become weaker by the end of the experiment (Table 1).

Herbage Yield

Cumulative yield differed among years, with the lowest yields obtained in 1995 averaging 3.6 Mg ha^{-1} for S50 and 2WK and 4.6 Mg ha^{-1} for the T75 and 6WK treatments; by 1997, yields were 7.6 and 8.2 Mg ha^{-1}, respectively (Fig. 3). In 1995, defoliation treatment influenced yield as did time during the grazing season. We grouped treatments into temporal (2WK and 6WK) and environmental (S50 and T75) categories to compare the influence of canopy development–based clips (environmental) with those based on fixed regrowth intervals (temporal). Canopy development–based criteria such as sward surface height would enable a producer to optimize production and quality. This is essentially a practice based on physiological time or phenology of the plant where productivity for an interval can be predicted when environmental conditions such as temperature or light are considered (Denison and Loomis, 1989). Clipping at fixed time intervals may be asynchronous with phenology and cause swards to be defoliated too early or too late in terms of leaf appearance and senescence attributes and could compromise persistence, productivity, and nutritive value of the sward (see Donaghy and Fulkerson, 1997). Defoliation based on sward surface height should be adjusted to the rate of leaf appearance and senescence of sward components.

The cumulative yield of swards managed on temporal (2WK and 6WK) compared with environmental (S50 and T75) removals differed significantly in 1995 based on single degree-of-freedom contrasts (Table 2). Slopes of temporal and environmental treatment data were not equal to zero, so data were fit to unequal slope models. The NOINT option of PROC MIXED provided estimates of intercepts and slopes to determine if modeled

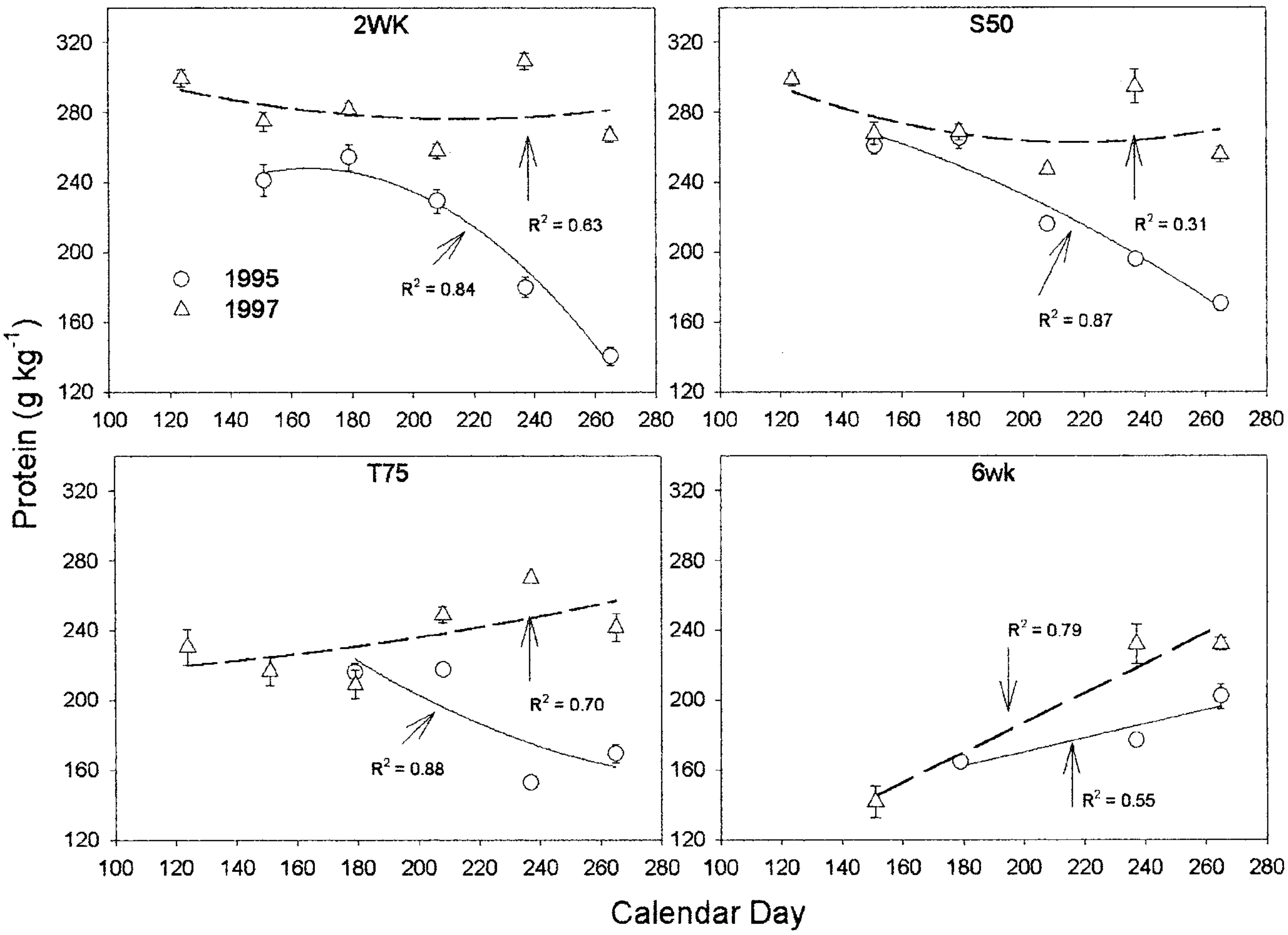

Fig. 5. Protein concentration in available herbage over the 1995 and 1997 growing season as a function of defoliation frequency. Vertical bars are standard error of the mean. 2WK, clipped at 2-wk intervals to a 5-cm residue; S50, 10-cm canopy clipped to 5-cm residue; T75, 20-cm canopy clipped to a 5-cm residue; 6WK, clipped at 6-wk intervals to a 5-cm residue.

lines differed, based on the single degree-of-freedom contrast of temporal vs. environmental treatments. The difference between the groupings increased over the course of the experiment (single degree-of-freedom contrast for temporal vs. environmental, F-value$_{1995}$ = 3.15 and F-value$_{1997}$ = 19.83). Treatments interacted with harvest date in that the number of harvests differed among treatments and increased each year over the course of the experiment. Number of harvests varied,

Table 2. *F*-values and significance of single degree-of-freedom contrasts from mixed-model procedures for the influence of defoliation regimes (temporal, 2WK and 6WK; or environmental, S50 and T75)† on cumulative herbage yield.

Contrast	1995	1996	1997
2WK vs. S50	<1	6.51**	38.29**
2WK vs. T75	35.53**	22.80**	101.70**
2WK vs. 6WK	16.90**	73.24**	106.96**
S50 vs. T75	21.90**	6.03**	15.69**
S50 vs. 6WK	9.70**	36.45**	17.66**
T75 vs. 6WK	1.71	10.33**	<1
Temp. vs. environ.	3.15	<1	19.83**

** Significant at the 0.01 level.
† 2WK, clipped at 2-wk intervals to a 5-cm residue; S50, 10-cm canopy clipped to 5-cm residue; T75, 20-cm canopy clipped to a 5-cm residue; 6WK, clipped at 6-wk intervals to a 5-cm residue.

in part, because temperatures and botanical composition of the sward influenced initiation of spring growth.

Inflection points (Table 3) and the pattern of IGR reflect change in botanical composition of the sward

Table 3. Regression parameters for the influence of time during the growing season on yield as a function of defoliation.

Defoliation treatment†	Year	Inflection point‡	Regression parameters§ α	β	k	R^2
		day of year	kg ha^{-1}	d^{-1}		
2WK	1995	191	4 591	49	0.020	0.997
	1996	162	6 669	34	0.022	0.999
	1997	152	7 560	13	0.017	0.996
S50	1995	184	4 023	216	0.292	0.996
	1996	161	7 535	21	0.189	0.999
	1997	154	8 631	13	0.017	0.997
T75	1995	180	5 665	93	0.252	0.999
	1996	150	7 512	12	0.016	0.983
	1997	157	10 735	6	0.012	0.996
6WK	1995	180	4 797	1 147	0.392	0.999
	1996	157	8 784	32	0.022	0.999
	1997	155	11 856	4	0.008	0.999

† 2WK, clipped at 2-wk intervals to a 5-cm residue; S50, 10-cm canopy clipped to 5-cm residue; T75, 20-cm canopy clipped to a 5-cm residue; 6WK, clipped at 6-wk intervals to a 5-cm residue.
‡ Estimate of $dy^2/dx^2 = 0$ for the Gompertz growth model equation.
§ Data were fit to the Gompertz growth model, and respective regression parameters were calculated.

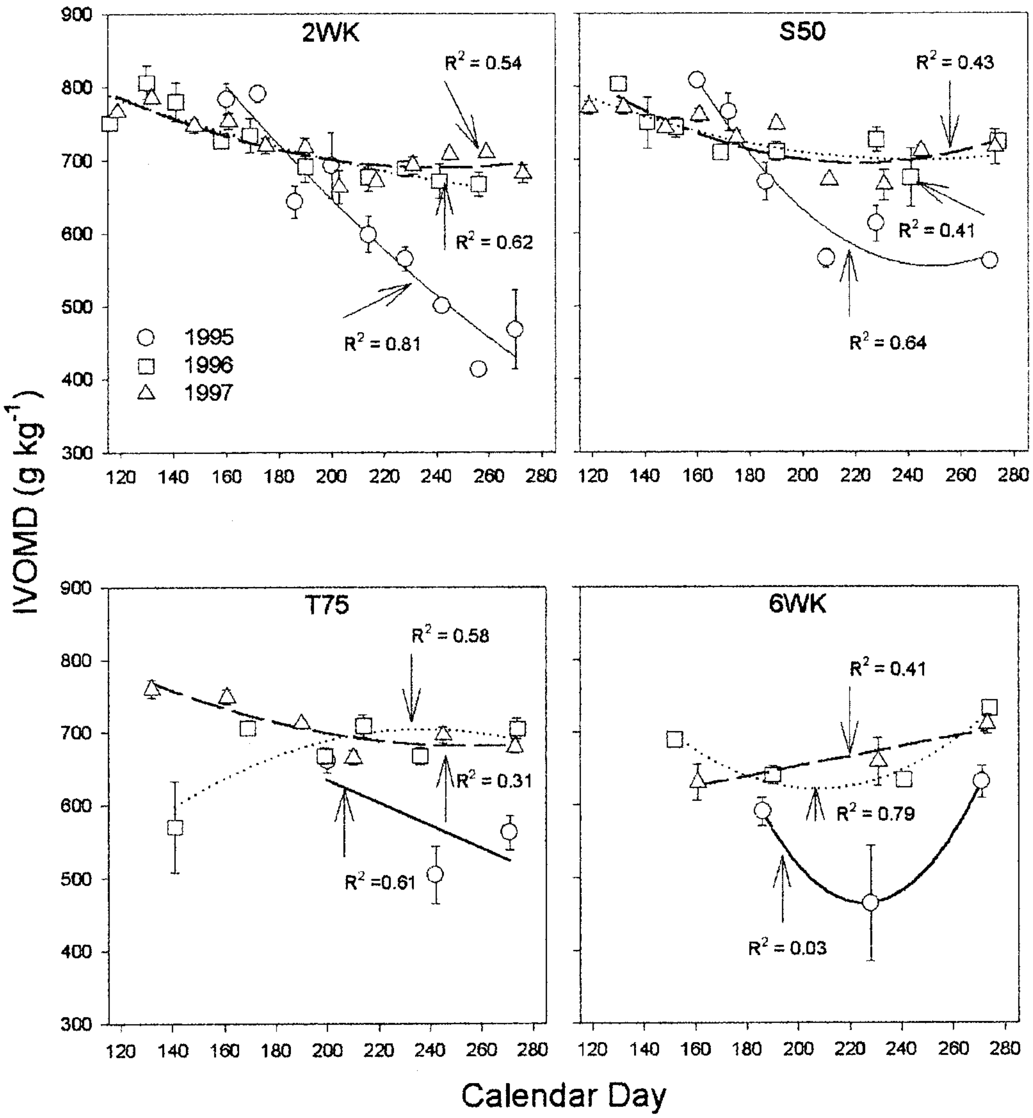

Fig. 6. In vitro organic matter disappearance (IVOMD) in available herbage from 1995 through 1997 growing season as a function of defoliation frequency. Vertical bars are standard error of the mean. 2WK, clipped at 2-wk intervals to a 5-cm residue; S50, 10-cm canopy clipped to 5-cm residue; T75, 20-cm canopy clipped to a 5-cm residue; 6WK, clipped at 6-wk intervals to a 5-cm residue.

over time. Maximum IGR occurred later in the growing season in 1995 when bermudagrass was a dominant sward component (mean of 50%) compared with subsequent years when bermudagrass often comprised <10% of the sward (Fig. 4). This agrees with previously reported results for bermudagrass (Belesky and Fedders, 1995b) where maximum growth rate (indicated by inflection points) occurred later in the growing season. The IGR patterns for 2WK and S50 treatments were similar to each other, as were those for the T75 and 6WK treatments. Maximum growth rates in 1995 were greatest for canopies clipped at 6WK (70 kg ha^{-1} d^{-1}) or managed as T75 and least at 2WK intervals (33 kg ha^{-1} d^{-1}) and S50 (45 kg ha^{-1} d^{-1}), but the trend was reversed by 1997. By this time, sward composition shifted away from bermudagrass to cool-season grasses and white clover. In 1997, the greatest IGR occurred in canopies clipped as S50 (47 kg ha^{-1} d^{-1}) but was only 37 kg ha^{-1} d^{-1} when clipped at 6WK intervals.

Nutritive Value

Crude protein concentration (only 1995 and 1997 are shown) was influenced by defoliation frequency (Fig. 5) and was greater in 1997 than in 1995, reflecting the botanical composition of the sward. Concentration stayed constant or increased during the 1997 growing season but declined in 1995 during the growing season in all clipping treatments except 6WK. The changes correspond to dominance of bermudagrass later in the growing season in 1995 and the dominance of white clover throughout the season in 1997. Crude protein was greater in the 2WK and S50 treatments than in T75 or 6WK treatments, reflecting the influence of leaf age on nutritive value. Much of the dietary protein can be lost from the rumen if insufficient energy is available. Nitrogen use is poor in grazed environments, with as much as 75 to 95% of N ingested by ruminants grazing temperate pastures lost via urine and feces (Ball and Ryden, 1984).

Nutritive value should be considered in terms of energy/protein ratio for efficient livestock production and N utilization and will be addressed elsewhere.

The IVOMD differed among years and defoliation regimes. In 1995, the IVOMDs of 2WK and S50 were similar to each other and ranged between 400 and 800 g kg^{-1}, depending on time of year, while IVOMDs of T75 and 6WK were similar and ranged between 450 and 650 g kg^{-1} (Fig. 6). Swards managed as S50 and 2WK were similar in 1996 and 1997and ranged between 700 and 800 g kg^{-1}. Swards managed as S50, T75, or 6WK intervals had lower IVOMD at midpoint in the season relative to the initial and final harvest, reflecting the dynamics of bermudagrass in the sward. Irrespective of treatment, IVOMD was lower in 1995 in part because of botanical composition, with less white clover and more bermudagrass relative to subsequent years.

The sward was grazed as part of the establishment process in 1994 before conducting the plot experiment. The botanical composition at that time was 50% bermudagrass, 5% white clover, and 45% other grasses and forbs. Lambs grazed for 17 d, with average daily gain (ADG) of 130 g d^{-1} for the first grazing interval. Sward composition was 70% bermudagrass, 20% white clover, and 10% other grasses and forbs before the second grazing interval where an ADG of 100 g $d^{-1}$was achieved. Combined, the two grazing intervals resulted in a total of 51 grazing days, averaging 111 lambs ha^{-1} with an ADG of 120 g d^{-1}. Lambs achieved a mean weight of 47 kg by 1 Sept. 1994, suggesting that swards with a substantial bermudagrass component had excellent potential for producing market-ready lambs by early autumn. This occurred despite IVOMD data suggesting that swards with substantial bermudagrass had lower in vitro disappearance. The fact that rumen fluid was collected from steers maintained on orchardgrass and alfalfa might have influenced the in vitro results obtained with bermudagrass. Sward nutritive value was less when managed on temporal rather than environmental considerations; single degree-of-freedom contrasts support this for IVOMD where swards were not different in 1995 (F-value = 1.83) but were by 1997 (F-value = 25.45).

Maintaining pure stands of sown forages in pasture in our region is difficult, and simple mixtures often are invaded by common species naturalized or native to the site. Weather patterns, management, and competition among plants in the stand create conditions allowing a range of native and naturalized forbs, grasses, and legumes to occupy gaps in the sward. Fluctuations in botanical composition over years often correlate with climatic conditions (Silvertown et al., 1994). Each of the components sown in our experiment could occupy resource patches by stolons or rhizomes and may not always occur at the same site in the sward over time. We proposed that complementary canopy architecture between the grass and legume and distinct seasonal yield distribution patterns between the cool- and warm-season grasses optimize light capture and sustain sward productivity over the growing season. Our results show that yields were greatest when cool-season species dominated the sward. The question of herbage availability may not be total yield, but yield distribution during the growing season.

Creating a self-regulating mixture of warm- and cool-season perennial forages may be one means of achieving some level of stability in the sward and might be useful where wide fluctuations in growing conditions occur among years. The relatively high stocking density possible with warm-season grasses is a benefit for cool season–based pasture systems as it provides buffer areas for grazers in times of limited cool-season forage availability.

ACKNOWLEDGMENTS

We thank G.D. Lambert, N.W. Snyder, D.P. Ruckle, K.N. Harless and R.C. Arnold for technical assistance with establishment, data collection, and nutritive value analyses.

REFERENCES

AOAC. 1990. Official methods of analysis. 15th ed. AOAC, Washington, DC.

Ball P.R., and J.C. Ryden. 1984. Nitrogen relationships in intensively managed temperate grasslands. Plant Soil 76:23–33.

Belesky, D.P., and J.M. Fedders. 1995a. Comparative growth analysis of cool- and warm-season grasses in a cool-temperate environment. Agron. J. 87:974–980.

Belesky, D.P., and J.M. Fedders. 1995b. Warm-season grass productivity and growth rate as influenced by canopy management. Agron. J. 87:42–48.

Bennett, O.L., E.L. Mathias, and G.A. Jung. 1976. Responses of perennial grasses and legumes to slope and microclimate. p. 476–491. *In* J. Luchok et al. (ed.) Hill lands. Proc. Int. Symp., Morgantown, WV. 3–9 Oct. 1976. WVU Books, Morgantown.

Brink, G.E., and T.E. Fairbrother. 1991. Yield and quality of subterranean clover and white clover–bermudagrass and tall fescue associations. J. Prod. Agric. 4:500–504.

Brown, R.H., and G.T. Byrd. 1990. Yield and botanical composition of alfalfa–bermudagrass mixtures. Agron. J. 82:1074–1079.

Denison, R.F., and R.S. Loomis. 1989. An integrative physiological model of alfalfa growth and development. Publ. 1926. Div. of Agric. and Nat. Resour., Univ. of California, Oakland.

Donaghy, D.J., and W.J. Fulkerson. 1997. The importance of water soluble carbohydrate reserves on regrowth and root growth of *Lolium perenne* (L.). Grass Forage Sci. 52:401–407.

Draper, N.R., and H. Smith. 1981. Applied regression analysis. 2nd ed. John Wiley & Sons, New York.

Dunnett, N.P., and J.P. Grime. 1999. Competition as an amplifier of short-term vegetation responses to climate: An experimental test. Funct. Ecol. 13:388–395.

George, J.R., K.M. Blanchet, R.M. Gettle, D.R. Buxton, and K.J. Moore. 1995. Yield and botanical composition of legume-interseeded vs. nitrogen-fertilized switchgrass. Agron. J. 87:1147–1153.

Hunt, R. 1982. Plant growth curves. The functional approach to plant growth analysis. Edward Arnold, London.

Jung, G.A., J.L. Griffin, R.E. Kocher, J.A. Shaffer, and C.F. Gross. 1985. Performance of switchgrass and bluestem cultivars mixed with cool-season species. Agron. J. 77:846–850.

Littell, R.C., G.A. Milliken, W.W. Stroup, and R.D. Wolfinger. 1996. SAS systems for mixed models. SAS Inst., Cary, NC.

Madakadze, I.C., B.E. Coulman, A.R. Mcelroy, K.A. Stewart, and D.L. Smith. 1998. Evaluation of selected warm-season grasses for biomass production in areas with a short growing season. Bioresour. Technol. 65:1–12.

Moore, J.E. 1970. Procedures for the two-stage in vitro digestion of forages. p. 5001.1–5001.3. *In* L.E. Harris (ed.) Nutrition research techniques for domestic and wild animals. Vol. 1. Utah State Univ., Logan.

Posler, G.L., A.W. Lenssen, and G.L. Fine. 1993. Forage yield, quality, compatibility, and persistence of warm-season grass–legume mixtures. Agron. J. 85:554–560.

Silvertown, J., M.E. Dodd, K. McConway, J. Potts, and M. Crawley. 1994. Rainfall, biomass variation and botanical community composition in the park grass experiment. Ecology 75:2430–2437.

Sleugh, B., K.J. Moore, J.R. George, and E.C. Brummer. 2000. Binary legume–grass mixtures improve forage yield, quality and seasonal distribution. Agron. J. 92:24–29.

Tilley, J.M.A., and R.A. Terry. 1963. A two-stage technique for the in vitro digestion of forage crops. J. Br. Grassl. Soc. 18:104–111.

Warren-Wilson, J. 1959. Analysis of spatial distribution of foliage by two-dimensional point quadrat. New Phytol. 58:92–101.

White, T.A., B.D. Campbell, and P.D. Kemp. 1997. Invasion of temperate grassland by a subtropical annual grass across an experimental matrix of water stress and disturbance. J. Veg. Sci. 8:847–854.